A CLINICAL EVALUATION OF CONE BEAM COMPUTED TOMOGRAPHY

by

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MASTER'S THESIS

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ABSTRACT

INTRODUCTION: Cone-Beam Computed Tomography (CBCT) has become a valuable diagnostic tool for endodontics. The literature generally supports the accuracy of this imaging modality. However, a few authors have indicated that CBCT may have limitations in representing the true clinical presentation. The aim of this descriptive pilot study was to compare pre-surgical CBCT images against the actual clinical presentation of the hard tissues. **METHOD**: Eleven patients requiring endodontic surgery warranting CBCT imaging at the Naval Postgraduate Dental School were consented and enrolled for this IRB approved study. This cohort consisted of following; 9 males, 2 females, ages 24-56, and 13 teeth (8 anterior, 5 posterior). Provider treatment notes and clinical photographs were used to generate an in vivo clinical presentation for each patient. An associate investigator directed 33 questions at three CBCT evaluators with differing experience levels. **RESULTS**: The evaluators correctly identified buccal plate perforations 85% (28/33 questions) of the time. Perforations in the anterior region were more often correctly identified (89%, 16/18 questions) when compared to those in posterior regions (80%, 12/15 questions). Communication between a lesion and the maxillary sinus were identified 53% (8/15 questions) of the time. The amount of remaining cortical bone was underestimated in every CBCT for all subjects (18/18 questions) with a mean underestimation of 1.7mm. **CONCLUSIONS**: CBCT is an additional instrument available to practitioners to assist in treatment planning. Evaluator understanding of CBCT technology combined with knowledge and experience in interpreting CBCT images are critical components for correctly using this diagnostic tool.

Key Words: CBCT, Cone Beam Computed Tomography, measurements in CBCT, Kodak 9000, endodontic surgery

INTRODUCTION

The accuracy of diagnostic imaging techniques is critical for providing optimum treatment planning. Historically, the periapical (PA) and angled PA radiographs, although limited by superimposition of structures and image distortion, have served this role (1). The panoramic radiograph offers a comprehensive view of maxillofacial structures, but suffers from the same shortfalls. The newest imaging available is cone-beam computed tomography (CBCT,) which offers three-dimensional (3D) images from orthogonal or custom views.

A number of authors have reported on the ability of CBCT to establish linear dimensions or evaluate anatomical structures or lesions using a variety of models. Ballrick et al (2) attached metallic markers to an *in vitro* model and reported that the differences in linear measurements (within 0.1mm) from CBCT images were clinically insignificant. Timock et al (3) found that buccal bone height and thickness varied by less than 0.3mm between CBCT and actual measurements taken from cadaver heads. Using dry skulls, Misch et al reported no significant differences between periodontal probing, CBCT images, or conventional radiography when measuring bone height (4), but CBCT tended to differ from the standard more than the other methods. Al-Ekrish and Ekram reported that CBCT's were more accurate than medical CT's, but still had an average error of 0.5mm, in comparing ridge width and height dimensions in dry skulls (5). Baumgartel et al reported (6) that CBCT significantly underestimated compound measurements.

The current body of literature lacks *in vivo* studies comparing CBCT images with clinical findings. The purpose of this descriptive case series was to investigate whether limited field of view (FOV) CBCT images were reliable indicators of the status of hard tissue found by direct observation using clinical photographs or measurements captured during endodontic surgery.

METHOD

Study approval was obtained from the Walter Reed National Military Medical Center (WRNMMC) Institutional Review Board. Consent was obtained from 11 patients (13 teeth) requiring endodontic surgery at the Naval Postgraduate Dental School (NPDS) meeting the following inclusion criteria: pathosis requiring endodontic surgery and a limited FOV CBCT. All CBCT images were taken independent of the study and in accordance with the 2010 American Association of Endodontists (AAE) and the American Association of Oral and Maxillofacial Radiologists (AAOMR) Joint Position Statement (7). Each patient required a unique surgical intervention.

No.	Gender	Age	Tooth	KV	mA	Secs	Voxel Size (mm)	Linear Measurement	Bone Perforation	Sinus Communication	Other
1	F	29	3	80	10	10.8	0.076		X	X* (MB, DB)	OC
2	M	46	3	85	10	10.8	0.100		X	X*(MB, DB)	
3	M	55	24, 25	90	10	10.8	0.100	VDB*, RM*			#25 CM
4	F	73	8	90	10	10.8	0.076		X		
5	M	27	10, 11	65	6	10.8	0.100	VDB	X*		
6	M	37	19	90	10	10.8	0.100	HDB	X		VRF
7	M	33	8	85	10	10.8	0.100		X		
8	M	56	30	70	10	10.8	0.076		X		FI
9	M	45	10	70	10	10.8	0.076	VDB*, RM	X		CM
10	M	48	13	90	10	10.8	0.100		X	X	
11	F	24	7	85	10	10.8	0.100		X		

Table 1. Subject demographics, CBCT settings and categories of questions

VDB - Vertical Dimension of Bone
RM - Root Measurement
HDB - Horizontal Dimension of Bone
* - 2 Responses
OC - Obturated Canals
CM - Canal Communicates with Mucosa
FI - Fractured Instrument
VRF - Vertical Root Fracture

The limited FOV CBCT images were captured by trained operators using a calibrated Carestream CS 9000 and associated software (Carestream, Atlanta, GA) with settings listed in

Table 1. These CBCT images were then downloaded from the WRNMMC server and de-identified using ONDemand3D (Cybermed, Reston, VA) software. Patient's clinical data (charts, notes, and clinical photographs) were also de-identified and placed into individual files and assigned a sequential identification number. The data within these clinical files provided the clinical presentation to which the corresponding 11 CBCT images were compared. This data was used by the study investigator to generate 3-6 specific questions for each of the 13 teeth. A total of 33 questions were compiled into a questionnaire. These questions were divided into 4 categories; linear measurements, bone perforations, sinus communications, and “other” (Table 1).

The CBCT images were uploaded onto a Dell Inspiron 15.6" laptop PC (Dell Computer Corporation, Round Rock, TX) with an external HP 2011x monitor (Hewlett-Packard, Palo Alto, CA). They were independently reviewed by 3 evaluators (general dentist, endodontist, oral maxillofacial radiologist) with varying experience in CBCT image interpretation. CBCT software instruction was provided by the study investigator. The evaluators were given unlimited time to view the images. For some questions, images that best identified an answer were captured and collated with the evaluators' response. Upon completion of viewing, the study investigator compared the 3 evaluator's answers to the database and collated the information.

RESULTS

Linear Measurements

Evaluators determined linear measurements using the software measurement tool. Six questions required evaluators to utilize the CBCT software to measure distances between a point on the tooth and the vertical height of cortical bone (Fig. 1A-B). These amounts were under reported in 18/18 questions and ranged from -1.0 to -3.5mm with a mean of -1.7mm (Fig. 1A,C).

One question relating to buccal bone thickness was underestimated (Fig. 1D-E) by an average of 1.0mm. Four questions asked the evaluators to determine the distance along root surfaces using the CEJ and margins of an external resorptive defect as endpoints. The mean CBCT measurements were less (-0.9mm) than the clinical presentation.

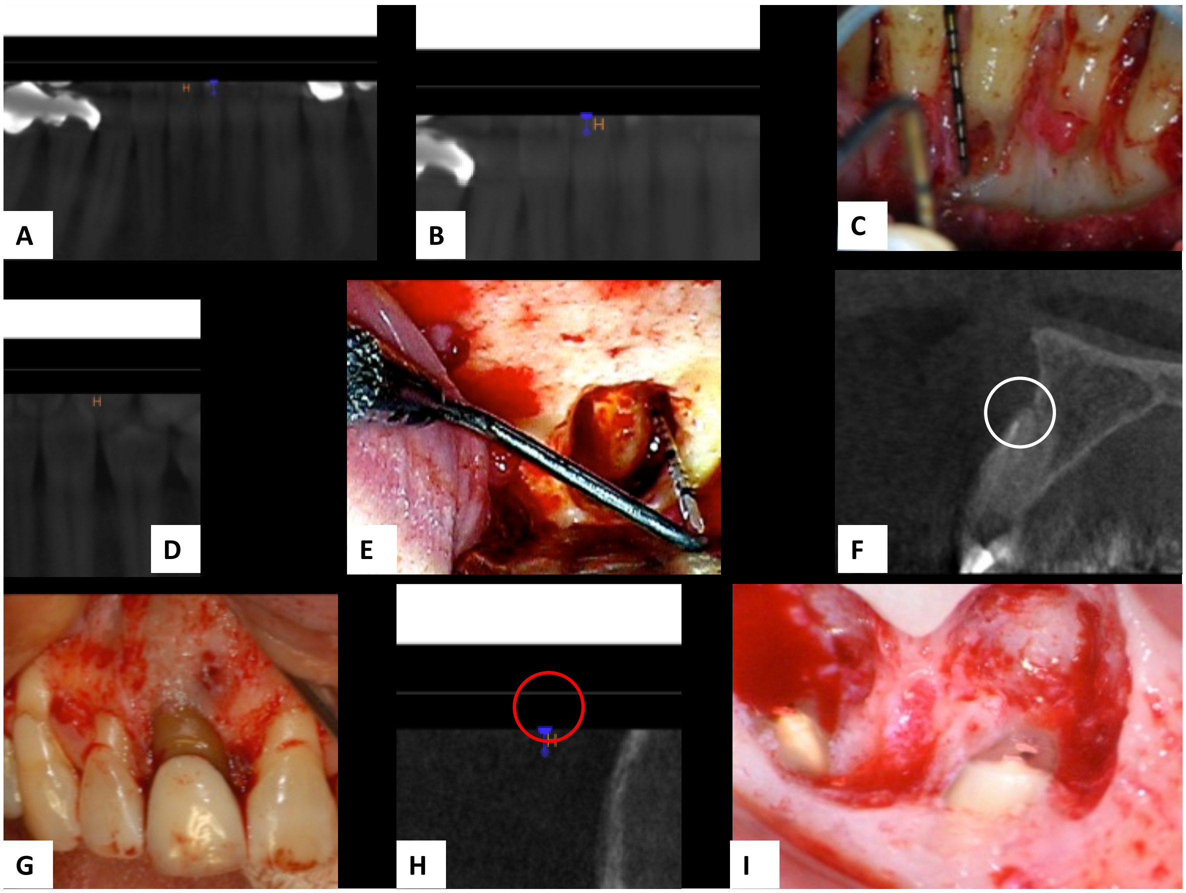

Figure 1. (A) CBCT image displaying a measured distance between the apical margin of a resorptive lesion and the incisal extent of the lingual cortical plate of #24. The software measurement tool established a distance of 3.5mm. (B) Tooth #25 of the same patient measuring inciso-apical distance of resorptive lesion. (C) Clinically, the resorptive defect on #24 was even with bone; therefore, evaluators had underestimated the bone by 3.5mm. On tooth #25, Length of resorptive defect measured on CBCT nearly equals the measured distance. (D-E) CBCT measurement averaged 1.6mm, whereas actual thickness of bone was 2.5mm (F-G) CBCT image and clinical photos incorrectly interpreted as buccal plate perforation of #8 (H-I) CBCT image incorrectly interpreted as sinus perforation. In actuality, thin layer of bone existed.

Bone Perforations

Eleven questions pertained to the presence or absence of buccal plate perforations in the CBCT images (Fig. 1 F-G). The overall accuracy of assessing either the presence or absence of a perforation was 85% (28/33). The accuracy was greater in the 6 anterior teeth (89%, 16/18) when compared to the 5 posterior teeth (80%, 12/15). There was no difference in the ability to detect anterior perforations from the sagittal or axial planes, where there was 89% (16/18) accuracy. In the posterior region, however, the coronal plane was slightly more accurate than the axial plane (80% vs. 75%). When all cases were combined, evaluators were slightly more accurate in correctly identifying intact bone (89%, 16/18) compared to bone perforations (80%, 12/15). The consistency between evaluators was high. Two identified 9 of 11 and one identified 10 of 11 perforations correctly.

Sinus Communications

The evaluators were asked 5 questions relating to the presence or absence of a communication between the maxillary sinus and an apical lesion (Fig. 1H-I). This was correctly assessed 53% (8/15) of the time. Actual communications were correctly reported 67% (2/3) of the time, whereas accuracy was only 50% (6/12) in non-communications. The oral maxillofacial radiologist was correct 80% (4/5) of the time while the 2 remaining dentists had an accuracy of 40% (4/10).

Other

Six questions pertained to unique situations encountered during surgery. Two concerned whether a true communication existed between the root canal and the overlying cortical bone once the soft tissue was reflected (Fig. 2A-D). In both cases, all evaluators responded correctly. Two questions involved identifying a foreign object in the root canal (Fig. 2E-F). These questions were correctly answered 83% of the time (5/6). The two final questions involved the identification of a vertical root fracture root and quantifying the number of root canals obturated. The three evaluators answered the 2 questions correctly (6/6).

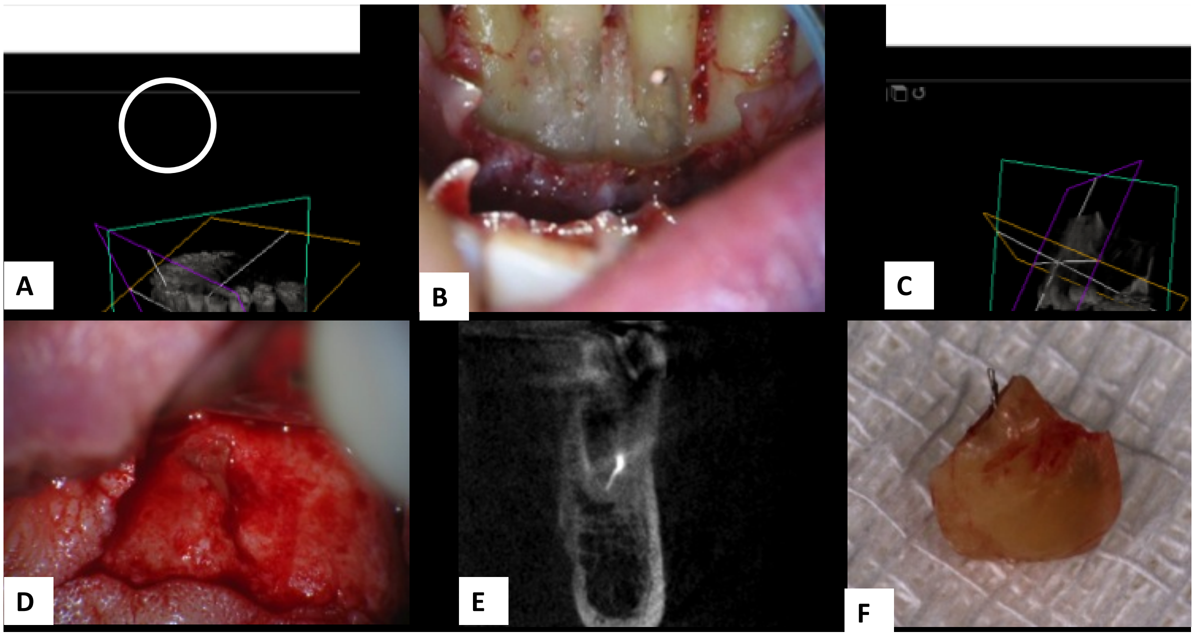

Figure 2. CBCT Images representing the "other" category. The CBCT and clinical images of #25. (A-B) All evaluators correctly assessed there was no hard tissue separating the canal space and gingival tissue. (C-D) All evaluators were correct in answering the same question for #10. (E-F) Two of the 3 evaluators correctly identified that the fractured instrument was in the ML canal of #30. The least experienced evaluator correctly answered that it was in a mesial canal, but was unable to identify buccal or lingual.

DISCUSSION

Several studies suggested that CBCT imaging allows practitioners to accurately predict clinical findings. In 2 comparative studies by Bornstein and colleagues, the reader could infer that there was a direct correlation between measurements gathered from the CBCT image and clinical findings (8,9). Simon et al (10) concluded that CBCT's may be more accurate than biopsy in differentiating cystic and granulomatous lesions. Kaya et al (11) used Hounsfield units to determine osseous healing associated with endodontic surgical sites; however, most agree that this measuring scale is not a capability of CBCT (12).

In this case series, discrepancies were noted between limited FOV CBCT's and the clinical presentation in 10 of 11 cases. The evaluators consistently underestimated remaining cortical bone height and thickness depicted by this technology. In one patient for example, all 3 evaluators underestimated the cortical bone height by 3.1 to 3.5mm (3.0mm mean). Given the fact that cementum and bone have similar densities, it is possible that the CBCT could not differentiate between these two hard tissues (13). The ability to detect the presence or absence of a communication between an apical lesion and the maxillary sinus was 53%. As in the case above where cortical bone was not visualized, bone separating a lesion from the sinus was also not detected. In this study, the ability to assess the presence or absence of a cortical plate perforation was 85%. Lueng et al were also unable to correctly detect the presence or absence of fenestrations using dry skulls (13). All of these examples may be related to the inability of CBCT technology to capture thin bone due to voxel averaging.

Cone beam image artifacts are distortions or inaccuracies unrelated to the object being imaged (14). In order to minimize artifacts, the CBCT's used in this study were taken by trained individuals using standard settings. The most likely artifact leading to underreported bone is the partial volume effect. This occurs when voxels include areas of differing, non-homogenous densities (14). Thin bone (high density) covering tooth structure may only encompass a fraction of a voxel while the majority of the voxel may be air or soft tissue (low density) (14,15,16). The CBCT reconstruction algorithm calculates weighted averages of voxel densities arriving at an overall density that is not representative of the actual object. Molen stated, "Factors such as partial volume averaging (partial volume effect), noise and artifacts make it impossible to achieve a resolution equal to the voxel size" (17). Ballrick et al reported that image resolution is dependent on the structure being 2-3x's larger than the voxel size selected. Selecting the smallest voxel size available minimizes this problem (2). Although this study utilized the smallest voxel sizes available (0.076 or 0.100mm.) inconsistencies between the recorded images and clinical presentations were noted.

Experience and training in interpreting CBCT images appeared to also play a role in this study. The 3 evaluator's responses were nearly identical. (It should be noted that the general dentist is the chairman of the NPDS Research Department with limited experience in CBCT imaging.) In the sole instance of variability among the evaluators, the radiologist correctly assessed sinus perforations 80% of the time vs. 40% for the endodontist and general dentist.

Incorrect assessment of remaining hard tissue can lead to unnecessary treatment. Pasqualini et al (18) stated if a buccal perforation exists following endodontic therapy, healing will be compromised. The treatment of choice therefore should be surgery. The presence of a fenestration based upon an erroneous CBCT reading could lead to unnecessary surgery. Similarly, a diagnosis based on the inadequate presence of bone, would change the prognosis from favorable to unfavorable. Alternatively, the unexpected appearance of buccal cortical bone could also complicate a surgical procedure.

A primary consideration in CBCT use is exposure to ionizing radiation. When compared to a posterior periapical radiograph, a CBCT exposes a patient to 1.5-6 times more radiation (19). In response to the potential misuse of this technology, the American Association of Endodontists (AAE) and the American Association of Oral and Maxillofacial Radiologists (AAOMR) released a joint statement identifying CBCT as a critical adjunct to patient care but advised caution, "...history and clinical examination must justify the use of a CBCT... (7)." The statement also recommends using a focused field of view (FOV) to increase image resolution and decrease radiation exposure. CBCT should only be used in cases where additional information cannot be gained from traditional methods.

All (18/18) bone measurements were underrepresented on CBCT images in this study. This case series also identified limitations in accuracy when evaluating buccal bone perforations and sinus exposures, which in part was due to partial voxel averaging. As with other diagnostic tools, there are limitations to CBCT. The three-dimensional image that CBCT provides has been an asset to endodontics and dentistry as a whole, but it is not without flaws when used to predict clinical findings.

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